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Improving Electrofishing Catch Consistency by Standardizing Power

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Abstract.—The electrical output of electrofishing equipment is commonly standardized by using either constant voltage or constant amperage. However, simplified circuit and wave theories of electricity suggest that standardization of power (wattage) available for transfer from water to fish may be critical for effective standardization of electrofishing. Electrofishing with standardized power ensures that constant power is transferable to fish regardless of water conditions. The in situ performance of standardized power output is poorly known. We used data collected by the interagency Long Term Resource Monitoring Program (LTRMP) in the upper Mississippi River system to assess the effectiveness of standardizing power output. The data consisted of 278 electrofishing collections, comprising 9,282 fishes in eight species groups, obtained during 1990 from main channel border, backwater, and tailwater aquatic areas in four reaches of the upper Mississippi River and one reach of the Illinois River. Variation in power output explained an average of 14.9% of catch variance for night electrofishing and 12.1% for day electrofishing. Three patterns in catch per unit effort were observed for different species: increasing catch with increasing power, decreasing catch with increasing power, and no power-related pattern. Therefore, in addition to reducing catch variation, controlling power output may provide some capability to select particular species. The LTRMP adopted standardized power output beginning in 1991; standardized power output is adjusted for variation in water conductivity and water temperature by reference to a simple chart. Our data suggest that by standardizing electrofishing power output, the LTRMP has eliminated substantial amounts of catch variation at virtually no additional cost.

The study reported here demonstrates that adoption of standardized power output (wattage), adjusted for local variation in conductivity and temperature, can reduce the variation in electrofishing catches. This is important because electrofishing is commonly used to monitor freshwater fish communities and populations, and because reduction of catch variance represents improvement in the efficiency of monitoring. Some electrofishing protocols require standardizing electrofishing output by selecting either constant voltage or constant amperage, but others do not even require a standardized output. Evaluation of standardization methods is critical to interpretation of electrofishing data.

Kolz (1989) presented a simple model of the transfer of power from water to fish that is based on simplified circuit and wave theories of electricity. The transfer of power from water to fish is most efficient when the ratio of conductivity of water to the effective conductivity of a fish is 1.0. Power settings must be adjusted for variations in water conductivity and temperature during every collection to ensure that constant power is transferred from water to fish.

The effective power transferable from water to fish can be used to standardize electrofishing. In theory, if a constant amount of power is transferred from water to fish, all external factors being the same, then fish of the same species and size should demonstrate approximately the same behavioral response to the electrical field (Kolz 1989). Kolz and Reynolds (1989) demonstrated that, under controlled conditions in the laboratory, the power density ($\mu W/cm^3$) transferred from water to goldfish *Carassius auratus* determined behavioral responses. Although important external factors are never constant outside the laboratory, the transfer of constant power may be the most effective practical approach to field standardization of electrofishing output. However, no field studies based on Kolz's (1989) power transfer model have been reported despite the practical importance of this issue.

We used electrofishing catch data collected by the interagency Long Term Resource Monitoring Program (LTRMP) during 1990 to identify the variation in catch that can be explained by variation in power output. The federal–state LTRMP was established, in part, to monitor fish populations and communities of the upper Mississippi River system. Fish sampling within the LTRMP is currently conducted within six study reaches on the upper Mississippi and Illinois rivers. Because the ultimate success of the LTRMP depends on the ability to make valid spatial and temporal com-

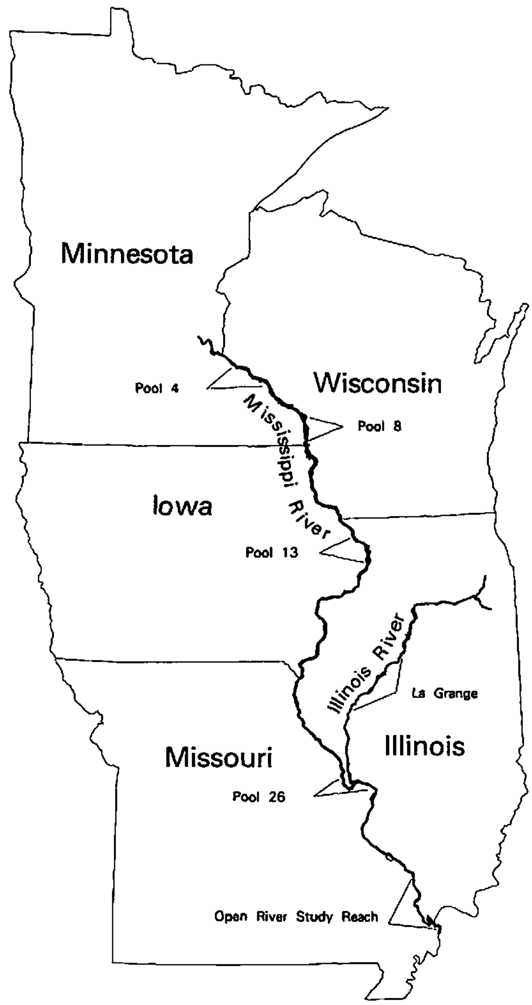

FIGURE 1.—During 1990, the Long Term Resource Monitoring Program conducted fish sampling in five study reaches along the upper Mississippi River (Pools 4, 8, 13, and 26, 38–72 km long) and the Illinois River (La Grange Pool, 115 km long). The open river study reach is 128 km long.

parisons, standardized sampling efforts are critical. Standardization of electrofishing is essential for collecting comparable data, but is complicated in the upper Mississippi River system by broad ranges in conductivity (250–700 μS/cm) and water temperature (15–35°C) during the sampling season. We used power correction factors calculated from the mismatch between the conductivities of fish and water at different temperatures to develop standardized power charts for use in standardizing LTRMP electrofishing. Our methods are easily modified to satisfy the objectives of other monitoring programs.

Methods

The LTRMP conducted electrofishing in five impounded study reaches along the upper Mississippi River (Navigation Pools 4, 8, 13, and 26) and the Illinois River (La Grange Pool; Figure 1) during 1990. In this study, we used data from electrofishing that was conducted in main channel border, backwater, and tailwater aquatic areas. Sampling was conducted at subjectively chosen, permanently fixed sites during 1990, which is common practice in freshwater fish monitoring programs; however, the LTRMP adopted a stratified random monitoring design beginning in 1993.

All electrofishing efforts had a duration of 15 min and covered a distance of approximately 200 m. Electrofishing was conducted between 0700 and 1300 hours (day) or from sunset to 0200 hours (night). Two people dipnetted fish from the electrical field. Two sampling efforts, separated by a 50-m buffer, were conducted within each site. A 5-d waiting period was required before a site was resampled to preclude effects of refractory fish behavior (Cross and Stott 1975).

All LTRMP electrofishing boats are identical with respect to length, shape, and electrical characteristics. These boats use 60-Hz pulsed DC, which induces at least some observable electrotaxis of fish toward the anodes. This configuration simplifies fish collection in highly turbid waters (20-600 nephelometric turbidity units). Peak output voltage is adjusted with a rheostat on a control box that rectifies, meters, and controls electrical output. Current varies with voltage and is not regulated independently. The average of peak voltage and peak current readings during collection were used to compute the average applied peak power. The duty cycle, defined as the percentage of time current flows, was 25% for all collections. The boats have two anode rings approximately 2 m forward of the bow, each carrying four 20.3-cm-long cylindrical stainless steel droppers having an outer diameter of 2.5 cm. The boat hull serves as the cathode. Electrical field measurements taken over deep open water indicate that LTRMP electrofishing boats produce an effective electrical field approximately 6.7 m wide at the anode array and 1.8 m deep. The effective electrical field size is defined as the area within which the voltage gradient is 0.1–1.0 V/cm (Novotny and Priegel 1974); in the LTRMP, field size is measured with an oscilloscope when an effective power transfer of 3,000 W is achieved (see below).

We used three power concepts that Kolz (1989) derived from simple circuit and wave theories of electricity. We used the simpler version of power transfer theory (Kolz 1989) based on total power output rather than on power density. This simplification ignores intractable spatial variation in power density and is equivalent to standardization of average power density within the electrical field. First, applied power P_a is the total power dissipated in the water and its contents (Kolz 1989); it is obtained from the product of peak volts and peak amps (W = VA) as observed from the output meters. Second, transferable power P_t is the portion of applied power that is theoretically available for transfer from water to fish under conditions defined by the simplified power transfer model (Kolz 1989). Third, the power output goal P_g is the calculated amount of power needed to compensate for differences in conductivity of water, fish, and water temperature to obtain a constant P_t.

A standardized power output goal is easily calculated from a predetermined P_t. Ambient water conductivity (C_a; APHA et al. 1985) is calculated as

$$C_a = C_s(1 + 0.0191[T-25]),$$

where C_s is the specific conductance (μS/cm) corrected to 25°C as measured by a conductivity meter, and T is water temperature (°C). Ambient conductivity is the uncorrected conductivity of water. Most conductivity meters produce measurements of C_s; a few meters measure C_a directly. Before P_g can be calculated, it is necessary to determine the mismatch ratio of the effective conductivity of fish to the ambient conductivity of water. Experiments conducted by Kolz and Reynolds (1989) indicate that the effective conductivity of live goldfish is 100–150 μS/cm; therefore, we assumed a value of 150 μS/cm for this study. The fish-to-water conductivity mismatch ratio (q) is given by

$$q = 150\ \mu\text{S}\cdot\text{cm}^{-1}/C_a.$$

Power is transferred most efficiently from water to fish when $q = 1$ (Kolz 1989). However, in most cases, $q \neq 1$, so P_a must be adjusted to achieve P_t. Kolz (1989) gave the multiplier for constant power (MCP) as

$$\text{MCP} = (1 + q)^2/4q. \qquad (1)$$

The amount of power transferable from water to fish is given by

$$P_t = P_a/\text{MCP}. \qquad (2)$$

Finally, the standardized power output goals for different water conditions are obtained by substituting P_g for P_a in equation (2) to obtain

$$P_g = P_t \times \text{MCP}. \qquad (3)$$

Given equation (3), values of P_g corresponding to appropriate ranges of C_a and T can be calculated. The first step is to select a value of P_t that is accepted as a standard. For use in the LTRMP, we selected the most successful unstandardized electrofishing collections and examined the corresponding P_t values using equation (2). Based on this analysis, the LTRMP adopted P_t = 3,000 W as its electrofishing standard beginning in 1991. We used equation (3) to create a chart of P_g values for field use (Appendix), and this chart has been used in the LTRMP since 1991. Standardization of P_t can be achieved by determining P_g from in situ measurements of conductivity and temperature and then adjusting electrofishing voltage so that $P_a = P_g$.

The lack of standardization of P_t in the LTRMP during 1990 resulted in data that can be used to assess the importance of standardizing P_t. Had P_t always been standardized, we could not have observed the variation necessary to assess associations between catch and P_t. For analytical convenience, we combined some closely related species into taxonomic groups. Data from La Grange Pool of the Illinois River contributed useful information to only 6 of 18 analyses; therefore, data from La Grange Pool were omitted from 12 analyses. Zero catches were included in all analyses. Catch per unit effort (CPUE) was calculated as fish per hour of electrofishing.

We estimated the effect of power variation on catch using ordinary least-squares regression analyses. We regressed $\log_{10}$(CPUE + 1) on the squared percentage, $\%P^2 = (100\ P_a/P_g)^2$, of the power output goal that was attained in samples. Our standard for transferable power, P_t = 3,000 W, was achieved, whenever $P_a = P_g$ or equivalently when $\%P = 100$. We used $\log_{10}$-transformed CPUE to help stabilize residual variance. We tested null hypotheses that population correlation coefficients ρ between $\log_{10}$(CPUE + 1) and $\%P^2$ equaled zero using the customary and equivalent F-tests of significance of the regression parameter for $\%P^2$, and we used sample coefficients of determination r^2 to assess the proportion of variation in $\log_{10}$(CPUE + 1) that was explained by variation in $\%P^2$.

Results

During 1990, five field stations conducted 278 electrofishing collections in main channel borders,

TABLE 1.—Total number of fish (catch) and frequency of occurrence (freq.) of eight taxa captured in 129 day and 149 night electrofishing collections obtained from backwater, main channel border, and tailwater aquatic areas of the upper Mississippi River system in 1990. The minimum catch per unit effort (CPUE; fish/h) was zero for all taxa and their maxima (max.) are given below. Sample coefficients of determination r^2 between $\log_{10}$(CPUE+1) and the squared percentage of power goal attained $\%P^2$ ($\%P = 100P_a/P_g$) can be interpreted as the proportion of the variation in $\log_{10}$(CPUE+1) that was explained by $\%P^2$. The signs of all correlation coefficients r are negative except where indicated by a + sign and for white bass captured during the day, for which $r \cong 0$.

	Day					Night				
			CPUE					CPUE		
Taxon	Catch	Freq.	Mean	Max.	r^2	Catch	Freq.	Mean	Max.	r^2
Bluegill *Lepomis macrochirus*	603	66	9.1	85	0.12	1,821	64	28.5	130	0.11[a]
Common carp *Cyprinus carpio*	406	76	5.3	26	0.08[b]	485	53	9.2	175	0.22
Black crappie *Pomoxis nigromaculatus* plus white crappie *P. annularis*	373	69	5.4	24	0.24+[b]	543	74	7.3	34	0.16+[bc] 0.19+[ab]
Freshwater drum *Aplodinotus grunniens*	91	34	2.7	10	0.08	258	49	5.3	18	0.09
Gizzard shad *Dorosoma cepedianum*	367	45	8.2	39	0.03	617	46	13.4	118	0.06
Largemouth bass *Micropterus salmoides*	366	65	5.6	29	0.06	385	59	6.5	48	0.03
Sauger *Stizostedion canadense* plus walleye *S. vitreum*	61	30	2.0	8	0.36+	2,514	105	23.9	222	0.29+[c] 0.09+[bd]
White bass *Morone chrysops*	104	34	3.1	33	<0.01[b]	288	48	6.0	89	0.13

[a] Contiguous (to the main channel) backwater aquatic area.
[b] Data from La Grange Pool, Illinois River, included.
[c] Main channel shoreline aquatic area; abundance may differ among aquatic areas.
[d] Tailwater shoreline aquatic area.

tailwaters, and backwater areas for the LTRMP, capturing 9,282 fishes within the eight taxa (Table 1); 149 night electrofishing efforts captured 6,911 fishes (74.5%), and 129 day efforts captured 2,371 fishes (25.5%). Among species, as much as 36% of the variation in $\log_{10}$(CPUE + 1) was explained by variation in the squared percentage of power goal attained ($\%P^2$; Table 1). Correlation coefficients between $\log_{10}$(CPUE + 1) and $\%P^2$ were significantly different ($P \leq 0.05$) from zero for all taxa except white bass captured by day electrofishing. Variation in $\%P^2$ explained slightly more variation in catch during night electrofishing (average $r^2 = 0.149$) than during day electrofishing (average $r^2 = 0.121$).

The fundamental nature of response of catch rate to power output differed among taxa. Three distinct patterns were observed: $\log_{10}$(CPUE + 1) decreased with increasing $\%P^2$, $\log_{10}$(CPUE + 1) increased with increasing $\%P^2$, and $\log_{10}$(CPUE + 1) seemed independent of $\%P^2$. For six taxa, $\log_{10}$(CPUE + 1) decreased with increasing $\%P^2$ during day and night electrofishing (Table 1). Catches of common carp captured in main channel border and backwater aquatic areas exemplified this pattern (Figure 2). Although catches were highly variable at any power output, the frequency of zero catches increased with increasing power. This phenomenon may have been caused by increased frequency of electronarcosis beyond the field of view at high power output or because of increased flight response at the periphery of the expanded electrical field. Catch rates of sauger plus walleye (Figure 3) and crappies were directly related to $\%P^2$. These species tend to select relatively deep water and increased power may result in more effective electrotaxis in such areas. Daytime catches of white bass seemed independent of power output. The signs of the correlations between $\log_{10}$(CPUE + 1) and $\%P^2$ were consistent within all taxa for which the correlations were significantly different from zero.

Discussion

Because electrofishing is an active capture method, controlling all variables—especially human behaviors affecting fish collection—is difficult if not impossible. However, standardization of procedures and controllable variables (e.g., electrical configuration and power output) is important to minimize bias and variation due to gear and operational practices.

The methods described in this study ensure that consistent power can be applied to fish regardless of local water conditions. Our data suggest that adoption of a standardized power transfer goal by the LTRMP during 1991 eliminated an overall average of 14.9% (night sampling) and 12.1% (day sampling) of the variation in $\log_{10}$(CPUE + 1) at virtually no additional cost. We believe that this

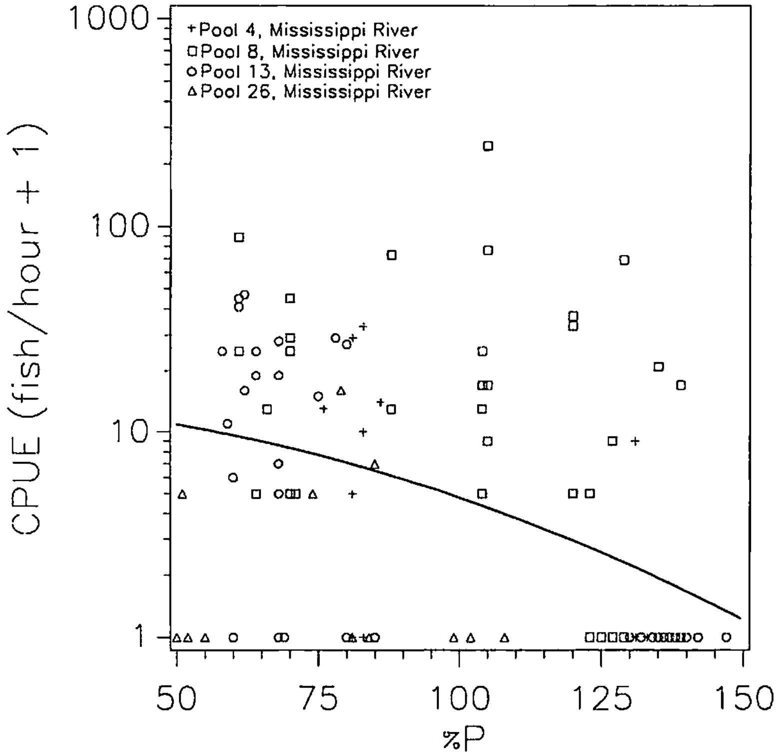

FIGURE 2.—Common carp captured during night electrofishing exemplify taxa for which $\log_{10}$(CPUE + 1) was inversely related to squared percent power output goal attained, $\%P^2$ ($\%P = 100P_a/P_g$), among sampling sites in main channel border and backwater aquatic areas of the upper Mississippi River system during 1990. When applied power is 100% of the power output goal ($\%P = 100$), 3,000 W are theoretically available for transfer from water to fish. The solid curve is the fitted regression of $\log_{10}$(CPUE + 1) on $\%P^2$.

is an important and cost-effective improvement in sampling precision.

The methods described by Kolz (1989) and used in this study are easily adapted to meet the needs of different sampling programs. The sample power chart (Appendix), which was designed for field use by LTRMP staff, can be modified to fit the specific needs of other electrofishing programs. Further, our results suggest that, if necessary, it may sometimes be possible to select for a particular species of fish by achieving a particular P_t.

Standardization of power seems warranted regardless of whether a particular species or many different species are sought. The results of this study suggest that electrofishing at different values of P_t can produce very different estimates of fish community composition. Therefore, where electrofishing is conducted to assess fish community composition, standardization seems critical for consistent measurement of composition regardless of selectivity patterns (Table 1) of constituent species.

Management decisions and research results can be no better than the data on which they are based; therefore, we believe that standardization of electrofishing merits further study. Our results were obtained from a monitoring program rather than from a rigidly controlled experiment. Therefore, we cannot assert that we isolated the effects of power variation from any confounding factors that might have existed. Besides the obvious need for additional field studies to examine the effects of power variation on capture of other species and in other aquatic systems, there is need for further controlled experimental study of the behavioral responses of fishes to electrical fields. For example, Kolz (1989) posed the hypothesis that the thresholds for behavioral responses such as fright–flight, electrotaxis, and tetany should conform to the concave-up curve of MCP as a function of the conductivity ratio q (equation 1). The results of laboratory experiments with goldfish were consistent with this hypothesis (Kolz and Reynolds 1989). However, our field data

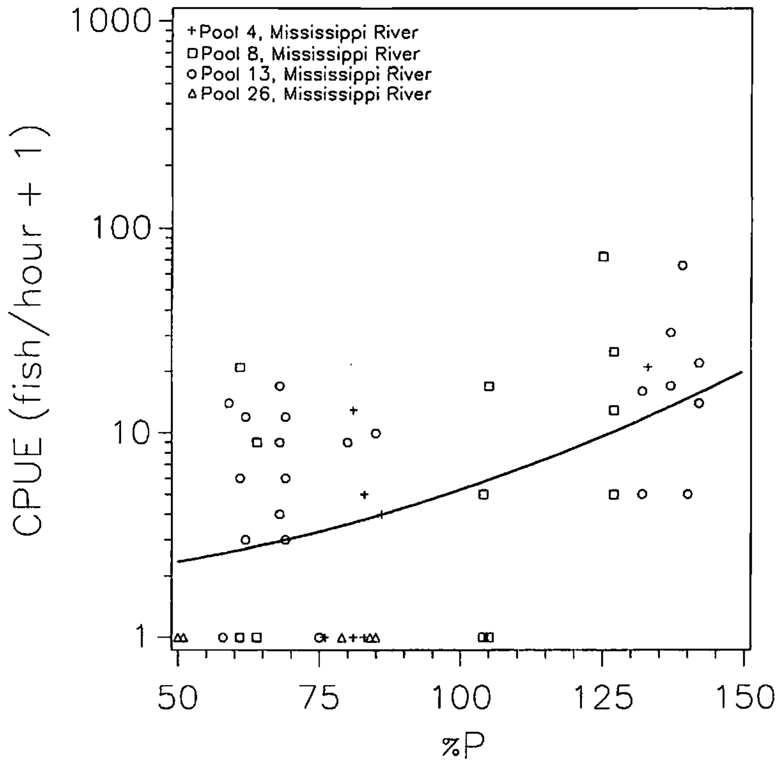

FIGURE 3.—Sauger plus walleye captured during night electrofishing exemplify taxa for which $\log_{10}$(CPUE + 1) was directly related to increasing squared percent power output attained, $\%P^2$ ($\%P = 100P_a/P_g$), among sampling sites in main channel border aquatic areas of the upper Mississippi River system during 1990. When applied power is 100% of the power output goal ($\%P$ = 100), 3,000 W are theoretically available for transfer from water to fish. The solid curve is the fitted regression of $\log_{10}$(CPUE + 1) on $\%P^2$.

could not be used to test that potentially important hypothesis for lack of ability to observe and record individual behavioral responses and for lack of control over spatial variations in abundance and other factors that might have been confounded with variations in q. Additional experimental examination of behavioral responses of other species may help explain the differences in signs of correlation coefficients (Table 1) that we observed. Although further study is needed, the cogency of power transfer theory (Kolz 1989), with support from our results and those of Kolz and Reynolds (1989), currently suggests that that theory provides the most logical basis for standardization of electrofishing output.

Acknowledgments

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Appendix: Electrofishing Power Goals

TABLE A.1.—Example power goal chart used by the Long Term Resource Monitoring Program for electrofishing in various water conditions (partial chart). Attainment of a power output goal under the appropriate combination of specific conductance (corrected to 25°C) and temperature provides a potential transfer of 3,000 W from water to fish.

Specific conductance (μS/cm)	Power output goal (W) at a temperature of:						
	5 °C	10 °C	15 °C	20 °C	25 °C	30 °C	35 °C
205	3,021	3,000	3,008	3,034	3,074	3,124	3,182
215	3,011	3,000	3,016	3,051	3,098	3,155	3,220
225	3,004	3,003	3,028	3,070	3,125	3,189	3,260
235	3,001	3,009	3,042	3,092	3,154	3,224	3,301
245	3,000	3,018	3,059	3,116	3,184	3,261	3,345
255	3,002	3,028	3,077	3,141	3,216	3,299	3,389
265	3,006	3,040	3,097	3,168	3,250	3,339	3,435
275	3,012	3,054	3,118	3,196	3,284	3,380	3,481
285	3,019	3,070	3,141	3,225	3,320	3,421	3,529
295	3,029	3,087	3,165	3,256	3,356	3,464	3,577
305	3,039	3,105	3,190	3,287	3,394	3,507	3,626
315	3,051	3,124	3,216	3,319	3,432	3,551	3,676